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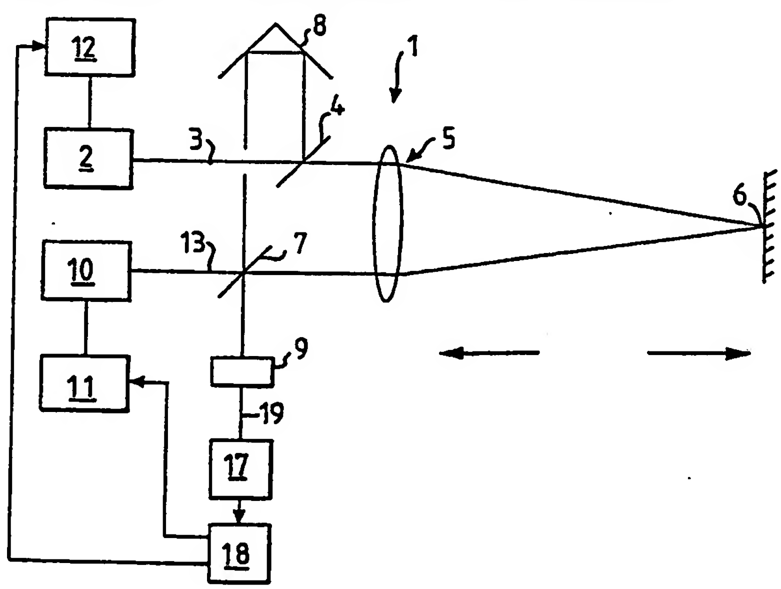

(57) Abstract

The invention relates to a method and apparatus for measuring an optical distance with the aid of a light beam transmitter (2) which generates a continuous, coherent, electromagnetic beam, at least during a measuring process. This beam is split and transmitted along two beam paths (3, 4, 8, 7 and 3, 4, 5, 6, 7) and the two beams are brought together at a detector (10), where they are added one to the other. The transmitter (2) is caused to change its wave number in time during at least one sequence, in order to determine a discrepancy between the two beam-paths. A phase shift corresponding to an instantaneous wave number is registered in an output signal from the detector (10). A measurement of the phase shift, and therewith the discrepancy, is obtained by measuring the number of occurrent interference fringes in a counter (10) and/or by measuring the time during a given sequence. The change in the wave number of the beam transmitted by the transmitter (2) is selected within a predetermined, accurately delimited wave number interval. The discrepancy is determined from the dependency of the phase change on the wave number change and/or the time.

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A method and apparatus for measuring optical distances

The present invention relates to a method for measuring an optical distance in accordance with the preamble of Claim 1, and also to apparatus for carrying out the method.

Methods and apparatus of the kind set forth in the respective preambles of the following method and apparatus claims and intended for establishing a discrepancy occurring between two optical paths are known to the art in several forms.

Such methods and apparatus are used normally for measuring distances, but can also be used for other purposes.

These known methods and apparatus are normally used to measure distances, but can also be used in other fields.

In order to keep the description of the known prior art within reasonable limits, the following description of known technical developments will be restricted to those relating to the measurement of distances.

Various methods are known to the art for determining distances optically, these methods varying in dependence on the magnitude of the distance to be measured, the accuracy to which the distance is to be measured and other requirements placed on the measuring process.

Because of the short wavelength of the laser source, its resolution in space is incomparably superior to that of other kinds of transmitter, e.g. ultrasonic and microwave transmitters.

There are principally two different groups of methods

which utilize laser beams, viz interferometric methods and modulation methods.

The interferometric methods can only be used for measuring distances which are shorter than approximately half the coherent length of the laser, i.e. in practice distances of less than about 50 meters. Since these methods are based on the known Michelson interferometer principle, it is necessary to transport a retroreflector on a slide or corresponding carrier, along the whole length of the measured path. During transportation of the retroreflector, one interference fringe is calculated for each half-wavelength of movement. The accumulated number of interference fringes will then give the total distance travelled, when the wavelength of the light beam is known.

A variant of this method utilizes two fixed wavelengths, a so-called two wavelength interferometer, where the difference frequency, phase dependency of the distance in relation to the transmitter, gives the distance. The method can be generalized to the use of more fixed wavelengths than two.

The possibility of utilizing the known Michelson interferometer principle suitably modified so that no movable parts are required and so as to obviate the need of moving the retroflective device, or mirror, in order to carry out a measuring process, will afford obvious advantages.

A method performed in accordance with the Michelson interferometer principle is described in US Patent 4 729 653 which, as prior art technique, describes that the light frequency of the laser beam is changed and that both the retroreflector attached to the target and the retroreflector used in the additional beam path for creating an interference pattern on a detector together with the beam

path to the retroreflector on the target may be fixed. Modulation of the light frequency of the laser beam is carried out during a given measuring time interval and the fringes resulting from the phase change at the detector are calculated during this time interval.

US 4 729 653 also describes a reference interferometer which is used to provide a measurement unit for carrying out a fringecount in the measuring interferometer. In this case the reference interferometer is constructed analogously with the main interferometer. This construction is an unfortunate one, since it means that the reference interferometer will have large dimensions, e.g. a length of about one meter, whereby it is impossible to avoid dimensional changes, unless taking expensive and far reaching rectifying measures. Because of its particular construction, or configuration, this known reference interferometer is prone to take up vibrations from the surroundings, which can be highly deleterious from the aspect of fringe pattern formation. Furthermore, in this case no reference is made as to how the measuring result will be influenced by possible movement of the object whose distance is to be measured, or of the corrective measures which need to be taken should the object be moved.

One object of the invention is to maintain control of wave number so as to obtain accurate measurements in an optimum fashion.

Another object of the invention is to provide a method which will allow the effects of distances to and movements of the measurement object to be separated so as to enable both to be determined.

A further object of the invention is to provide a reference interferometer which has small dimensions and which

is therefore less sensitive or vulnerable to vibration.

Still a further object of the invention is to obtain a distinct output signal from the reference interferometer detector. Since the reference interferometer has small dimensions, the time distance between each fringe count will be relatively long, and definitely much longer than the time distance from the measuring interferometer. The more distinct the indication of the fringes from the reference interferometer the better.

The aforesaid objects are achieved with a method according to this invention which has the characterizing features set forth in Claim 1. Other features and developments of the invention are set forth in the following claims, which also include apparatus claims defining the characteristic features of inventive apparatus by means of which the inventive method can be put into effect.

The ability to select a wave number interval affords the advantage of enabling the inverval to be predetermined with extreme accuracy, for instance with the aid of atomic references.

The invention will now be described in more detail with reference to the accompanying drawings, in which
Figure 1 illustrates highly schematically an interferometer arrangement which utilizes a single mode laser and which is complemented in accordance with the inventive proposals;
Figure 2 is a diagram which is intended for use when determining occurrent discrepancies; and
Figure 3 is a block schematic illustrative of one embodiment of an electric circuit for the interferometer arrangement shown in Figure 1.

Figure 1 illustrates an exemplifying embodiment of an interferometer-type distance measuring apparatus, generally referenced 1 in the Figure, comprising a beam source 2, which should have the form of a single mode laser, a semiconductor laser or a diode laser, and which transmits continuously a coherent light beam 3, which is split into two beam parts by a beam splitter 4. One of these beam parts passes through a focusing system 5 to a measuring point 6, from where the beam is reflected back through the focusing system and through a further beam splitter 7 and onto a detector 10. The other beam part is passed onto a stationary reflector 8 which directs said beam onto the further beam splitter 7, which in turn reflects the beam onto the detector 10. The beam 13 located between the beam splitter 7 and the detector 10 will then include interfering light rays obtained from the two beam paths.

The interfering light beam 13 exiting from the beam splitter 7 is detected homodynamically in a progressive manner as the wavelength of the coherent light changes. The detector 10 is preferably placed in the centre of the interference pattern and is small enough to discern a fringe separately. The detector 10 is connected to a counter 11. The transmitting beam source 2 is also connected to a control circuit 12, which enables the given wave number of the light beam to be changed during the time period taken to determine a discrepancy between the optical wave paths of the aforesaid two beam paths.

The aforedescribed arrangement is thus based on interference between a beam which is reflected from the point whose distance is to be measured, a so-called object beam, and a reference beam, which beams are brought together and then directed onto the detector 10.

Assume that these two beams each illuminate the detector at intensities "I_{obj}" and I_{ref}", respectively. When these beams illuminate the detector simultaneously, because of interference the intensity will be

$$I_{det} = I_{obj} + I_{ref} + 2 \times \sqrt{I_{obj} I_{ref}}\ |\gamma|\ \cos(2\pi kx) \qquad (1)$$

It is assumed here that the two beams are spaced coherently across the surface of the detector, i.e. the detector has an area which includes at most one fringe and lies in the centre of the interference pattern.

$|\gamma|$ is then the value of the degree of coherence of the two beams for the time delay which applies when the path difference therebetween is "x".

$k = 1/\lambda$ is the wave number for the light source of wave length "λ".

This principle beam path is the same as that in a traditional Michelson interferometer array, although measuring procedures differ essentially, since it is not necessary to move a mirror or like retroreflector from one position to another, when determining measurements. The fundamental principle in fact requires no movable parts to be present.

Instead of varying the distance "x" (cf equation 1) at a known fixed wave number "k" and counting the number of interference fringes progressively as the phase passes "2π", the wave number "k" is now varied under conditions which are known in general, whereas the distance "x" is fixed and is determined from the variation of the phase term according to equation 1.

Accuracy is contingent on the extreme values of the change in laser wave number that takes place during the measuring period.

Assume that these extreme values are "k_a" and "k_b" respectively. A fringe counter will then register $N = |k_a - k_b| x$ fringes.

Since the unknown geometric distance "d" is x/2n, where "n" is the refractive index of the propagation medium at the prevailing wave number, the following relationship will be obtained:

$$d = N/(2n\ |k_a - k_b|) \qquad (2)$$

Without fringe interpolation, the length resolution will then be

$$\Delta d = 1/(2n\ |k_a - k_b|).$$

In order to achieve a resolution of, for instance, one millimeter in air by solely counting whole number fringes, it is necessary, according to equation 2, for the beam source to vary its wave number by 5 cm^{-1}, which corresponds to a frequency change of 150 GHz. This is about 100 times too much for the visible gas laser available at present times. A dye laser would be capable of managing this frequency change, although not in the short time desired. This type of laser is also complicated, expensive and clumsy.

This problem is best solved with a single mode semiconductor laser. Such a laser is able to sweep over the wave number range concerned in some tens of nanoseconds (or at a slower speed if desired).

GaAlAs-diode lasers are excellent in this context and are also the cheapest lasers capable of being procured.

The desired wave number sweep can be achieved by rapidly

changing the driving current of the semiconductor laser, which results in an adiabatic change in the optical length of the laser cavity, and therewith a continuous wave number scan.

In the case of a commercially available GaAlAs-laser which has a 40 mW continuous optical output in a single mode, the desired result can be achieved with change in the laser 100 mA drive current of only about 20 mA.

One problem which must be taken into account in the case of the cheaper GaAlAs-lasers, is that of wavelength--dependent mode jump. This problem can be avoided, by using the laser at those individual temperatures and drive currents at which the laser exhibits mode stability. A simpler, although somewhat more expensive method is one of using a distributed feedback (DFB) laser. This laser will always oscillate in one and the same longitudinal mode. Other more sophisticated technical solutions of the mode jump problem are also to be found, of which one will be described in more detail hereinafter.

A reference cell is used to measure the change in wave number required to effect a distance calculation in accordance with equation 2. The beam transmitter 2 shall also be capable of transmitting a light beam with wave number change for the purpose of formulating a wave number interval located within pre-determined limits, wherewith the aforesaid discrepancy can be determined from the dependency of the phase change on the change in wave number.

In order to enable the wave number interval to be measured when the counter 11 is activated, the light beam transmitter 2, which is a spectrally scanning, electromagnetic, coherent light source, is controlled by a reference inter-

ferometer 9, which in accordance with the invention has high finesse. The reference interferometer 9 coacts with a detector 17, which is, in turn, connected to a start/stop circuit 18.

Instead of a reference interferometer 9 there may be used, alternatively, a gas spectrum, in order to give rise to the dispersive characteristics from which a wave number interval can be determined.. An arrangement for this purpose will include a reference cell which is filled with an atomic or molecular gas that has absorption frequencies in the working range of the laser. The reference spectrum can be programmed into a computer which is programmed to control the laser wave number on the basis of the reference signal.

One example of a reference interferometer with which the wave number change of the laser can be monitored and determined is an optical reference cavity, which may, for instance, consist of a thin high-finesse etalon or a confocal mirror arrangement that comprises two mutually facing concave mirrors, each of which has its mirror radius located on the opposite mirror.

Figure 2 shows the shape of the beat signal on the light beam 13 in relation to the mean value 20, and it is assumed that the light source 2 transmits a light beam which has a varying wave number k = f(t) and that during transmission of wave number "k1" there is formed a fringe 14 and that during a time section in which the wave number is "k2" there is formed a fringe 15, and that during a time section in which the wave number is "k3" there is formed a fringe 16.

The respective distances between these fringes will constitute a measurement of the evaluated discrepancy.

It shall also be possible to cause the beam transmitter 2 to change its wave number during said time section as a continuous (linear) function with respect to time, and also to be able to give the wave number change a sawtooth or a triangular shape.

It is also possible to determine the absolute value of the discrepancy in a first measuring step and to store this value in the counter 11, and to determine the absolute value of the discrepancy in a second measuring step and to store also this value in the counter and then establish the discrepancy difference.

This establishment of the discrepancy need not solely be used to measure geometric distances, but can also be used to determine prevailing temperatures. For instance, if it is assumed that the optical path 4, 5, 6 and 7 consists of an optical fibre, a change in temperature will result in a change in length of the fibre which, in turn, will result in a discrepancy change.

The same applies when using an established discrepancy to determine prevailing pressure values.

This can be effected by placing on the end of an optical fibre an optical component whose optical length will change when pressure is applied thereto, said fibre representing the measurement path.

When the discrepancy is to be used to determine a change in magnetic field, it is suggested that an optical fibre is coated or doped with a magnetically actuable material which, under the influence of the magnetic field, will cause a change in the volume index, refractive index or shape of the optical fibre. This change can then be used to determine an occurrent discrepancy between the two optical paths.

Figure 2 illustrates the shape of the light beam 19 obtained from the high-finesse reference interferometer 9. When applying in the circuit 18 a discriminator level which corresponds to 21, it is possible to determine the value of the wave number interval $|k_4-k_5|$ and also wave number intervals which are multiples.

The spectral range in an etalon, $\Delta\nu_E$ is equal to c/2ns, and in a confocal mirror arrangement $\Delta\nu_{CF}$ is equal to c/4ns, where "c" is the speed of light and "n" is the refractive index in the reference interferometer, and "s" is the geometric flat distance.

When a longitudinal resolution of 1 mm is chosen, there is preferably used a reference interferometer, e.g. an etalon, that has a free spectral range of 5 cm^{-1} (150 GHz). With adjacent transmission spikes (or more specifically on the flanks of the spikes) as triggers for starting and stopping the fringe counter of the homodyne detector, the counter value will be equal to the distance measured, in millimeters. This numerical value can therefore be sent immediately to a display, without needing to be processed arithmetically.

When controlled by such a reference interferometer, the laser will sweep over a free spectral area of $\Delta k = 1/2ns$ (when the interferometer is of the Fabry-Perot kind).

When the etalon used in this example is an air etalon, it will require a thickness of one millimeter.

One advantage with using an air interferometer as a length interpreter in this context is that temperature and moisture will influence its optical wavelengths by the same scale factor n as the optical wavelength of the

distance being measured. Measuring errors caused by temperature and moisture are therefore brought to a minimum.

Satisfactory results can also be obtained when using a reference interferometer whose length is a multiple N_{FP} of one millimeter. In this case, however, it is necessary also to equip the reference interferometer with a counter, so that upon the occurrence of an activating reference fringe, both counter registers will be set to zero, whereafter the counter of the homodyne counter is stopped (or read off) after the appearance of N_{FP} fringes in the reference cavity. In this general case, the distance is obtained from the relationship

$$D = s \times N/N_{FP} \qquad (3)$$

The working function of the reference interferometer can be illustrated with the following concrete example, in which the true distance to be measured is 9 1/3 meters.

Let us imagine an arrangement which is equipped with a reference interferometer in the form of an etalon with a flat distance of 10 mm. In the case of a low resolution measurement process in which two adjacent resonance ordinal numbers form respective triggers for starting and stopping the fringe counter, the measuring result will be 933 fringes. The distance derived from equation (3) will then be

$$d(mm) = 10 \times 933/1; \text{ i.e. } 9.33 \pm 0.01 \text{ m.}$$

In the case of this example, the wave number of the laser varied during the measuring period according to the following relationship:

$|k_a-k_b| = 1 \times 1/2ns = 0,5\ cm^{-1}$.

Using the same arrangement, a more detailed measurement is then made by setting the transmission counter of the reference interferometer to twenty (20), so that the stop signal will not be sent to the homodyne fringe counter until the reference interferometer has counted to 20 resonance ordinals. This means that the variation of the laser wave number $|k_a-k_b|$ during the measuring period will now instead equal $20 \times 1/2ns = 10\ cm^{-1}$. In this case, the number of fringers counted will be 18666. Substitution in equation (3) will then give

$$d(mm) = 10 \times 18666720;\ i.e.\ 9,3330 \pm 0,0005\ m.$$

The optical wavelength of the reference light (beam) will have been taken into account when constructing the distance measuring apparatus used, such that a specific point on the arrangement will constitute a zero point when determining or measuring distances. This point will, at the same time, constitute the pivot centre in horizontal and vertical directions, so that the arrangement is able to produce data for describing space in polar coordinates, with the aid of angle sensors herefor.

The exact thickness s̲ of a reference interferometer can be measured with the aid of equation (3) when measuring a distance d̲ of known value. This calibration value of s̲ can then either be used in conjunction with subsequent measuring operations or s̲ can be adjusted to an even number, by rotating the reference interferometer away from the optical axis, such that its effective s-value will change in accordance with

$$s' = s/\cos \Theta$$

where θ is the angle between the optical axis and the normal vectors of the interferometer plates.

When a sensitive detector is used, such as an avalanche diode or a photomultiplier, the aforedescribed distance measuring apparatus is able to operate without a retroreflector at the point from which a distance is measured, even in the case of long distances where the time coherence becomes the limiting factor.

An optical narrow-band detector system may then be necessary, so as to avoid detection saturation as a result of background illumination.

According to the coherent detection principle, the signal contribution from the weak and diffuse reflected light beam is multiplied by the interference with the reference light beam (see equation 1). For instance, in the case of an arrangement in which $I_{ref} = 1$ mW, the signal component can be 1 μW for an object intensity as small as 2.5×10^{-10}W; this is only true when the coherence surface area covers the whole detector.

Space coherence can be realized by focusing the laser beam onto the measuring point (which can be done automatically) and by making the receiver aperture as small as the diameter of the beam transmitted. Diffraction from the reflecting measuring point will then guarantee that the coherence surface area on the fringe detector will be sufficiently large and, at the same time, that the intensity of the laser beam is utilized to an optimum (the laser is assumed to oscillate in the fundamental mode TEM_{00}).

In practice, the speed at which distances can be measured with the above discussed inventive arrangement is not

limited by the beam source and its modulation, since in the case of a diode laser it is possible to achieve sweep speeds as high as 5 cm^{-1} per microsecond with the aid of primitive means. Consequently, this time limitation lies instead in the inertia of the fringe detection system.

Assume in the following exemplifying calculation that this detection system is 200 MHz (a typical value for an integrated avalanche diode/amplifying system). Consequently, with a distance resolution of $\Delta d = 1$ mm and a measuring range of 0-20 m, this will enable 10 000 independent measurements to be taken each second. For distances of 0-2 m, 100,000 measurements per second can be taken. Consequently, in practice the measuring time can be dimensioned in accordance with the following relationship

$$t_{meas.} = d/\Delta d \times 1/\text{detection band width} \qquad (4)$$

When utilizing fringe interpolation electronics, an advantage will, of course, be afforded when the interpolation resolution factor is included in equation (4).

In the above example, where the distance measured was 9 1/3 m, the optimum measuring time in the case of low and high resolution measuring processes will be 5 microseconds and 100 microseconds respectively when using a 200 MHz detection system.

When the time section between two successive interference fringes is so short as to be comparable with the delay time interval of the object light beam, it is necessary to take into account the phase shift that occurs as a result of the finite speed c of the beam. This potential error source is eliminated completely, when the laser wave number is varied linearly with time. During a time section $\Delta t = 2d/c$, at least the value of dk/dt shall be the same as that obtained during the same time section at the end of the measuring period.

In the case of an arrangement which is constructed to carry out the aforedescribed distance measuring method, the light beam source - seen spectrally - can also be easily stopped and locked to a fixed beam wave-number, determined by the reference cell and its resonance frequencies. This converts the distance measuring apparatus to a high resolution Michelson laser-interferometer, with all its possibilities. With the aid of a built-in timer, the interferometer can then be used as a Doppler velocimeter and vibration analyser. Combinations of this measuring mode and the spectral sweeping measuring mode may be relevant in the case of certain applications.

The diode laser is operated with low-voltage electronic devices and can therefore be readily controlled with the aid of a microprocessor, which is operated with software programmed with the user-determined functions in accordance with the method described here.

It will also be understood that the distance to be measured need not necessarily be a geometric distance, but may equally as well be the length of an optical fibre, either in part or as a whole. Sensors which are intended to detect temperature, pressure or some other magnitude and which are able to influence the optical wavelength in the fibre, either directly or indirectly, can be used advantageously as an interferometer.

Either the optical path travelled by the object beam will consist of a single fibre, which in this case will form the sensor totally, or the reference beam may also be transported through a fibre. In this latter case, the two fibres may either be identical to one another, but placed in two mutually separate physical environments which are to be compared, or may be mutually different (e.g. in length) and placed in one and the same physical environ-

ment, to function as a calibrated probe. One variant of this probe will comprise a single, long single-mode fibre which transports the laser beam from the transmitter to the object whose distance is to be measured (this distance may be in the order of miles). The fibre is joined together with a fibre stump or slug, the length or construction of which decides the sensitivity of the sensor. The beam reflected from the join can then be the reference beam and the beam reflected from the stump end the object beam, both of these beams being transported back along the long fibre to the transmitter, where they are detected.

In present day usage of fibre sensors, the sensitivity of the sensor is determined once and for all during its manufacture. Such sensors, however, are normally too sensitive to be used in different contexts. When carrying out optical distance measuring operations in accordance with the described method, however, the sensivity of the same sensor can be reduced dynamically down to a suitable or appropriate level, as required.

Figure 3 illustrates schematically one embodiment of the electrical control and detection system utilized in the interference distance measuring apparatus illustrated in Figure 1. When practicing the illustrated solution, no quotient is formed between the result from the units 10, 11 in the measuring section of the interference distance meter, and neither is any reference interference frequency engendered. Instead, a well defined wave-number sweep number is taken as a reference. A thin high-finesse etalon, e.g. an etalon having a free spectral range of 3 cm^{-1} (1.6 mm air gap or 1 mm solid glass) is able to define the measuring sweep interval to one part in 100 000. This is roughly what is required to take full advantage of a fixed digital distance resolution of, e.g. 0.2 mm in a measuring range of, e.g. 10 m.

In order to enable distances from diffuse targets to be measured, i.e. targets from which the object signals are relatively weak, the detecting system has a high amplification over a narrow band width centred on a fixed frequency f_s (e.g. 15 MHz). Consequently, the laser sweep system is constructed to tune the wave number to a speed which is determined strictly by the incoming object signal. According to equation (1), the interference frequency is contingent on the wave-number sweep velocity dk/df and also on each object movement component along the laser beam dx/dt. Consequently, the total number of fringes counted during the time Δt taken to tune the laser to the predetermined wave number interval Δk will be

$$N = 2d \cdot \Delta k + 2kv \cdot \Delta t \qquad (5)$$

In this case v (= 0.5 . dx/dt) is the linear object movement along the laser beam. Since the present system has a fixed fringe count rate, the measuring time Δt can be expressed as N/f_s. The equation (5) will then be

$$N = 2d \cdot \Delta k + 2kv\, N/f_s.$$

The effect of the linear object movement v can be separated from the effect of the sweep rate dk/dt, by carrying out two consecutive measurements with the sweep rate sign reversed. If it is assumed that the total number of fringes in the two consecutive sweeps is N_1 and N_2 at equal wave number intervals Δk, the equation (6) will give

$$N_1 = 2d \cdot \Delta k/(1-2kv/f_s) \qquad (6)$$

$$N_2 = 2d \cdot \Delta k/(1+2kv/f_s) \qquad (7)$$

By solving v̲ and d̲ in the equation system (7) and defining q̲ as

$$q = (N_1-N_2)/(N_1+N_2)$$

there is obtained

$$v = f_s\ q/2k \qquad (8)$$

$$d = N_1\ (1+q)/2\Delta k \qquad (9)$$

At least two equations which can be suitably combined for calculating both the distance to the object and also possible movement of the object can then be compiled by carrying out and combining at least two of the following measuring procedures:

A. the time taken to effect the wave number change within the well defined wave number interval is measured during a separate sequence;

B. the time taken to effect the wave number change with the sign reversed relative to procedure A within a well--defined wave number interval - which need not be the same as that under point B - is measured during a separate sequence;

C. fringes are counted over a given time period at a fixed wave number during a separate sequence;

D. the fringe pattern on the detector is held stable, by changing the absolute frequency of the laser so as to maintain this stability and the time is measured during a given wave number interval.

In the case of the Figure 3 embodiment, the laser 30 is, for instance, of the same kind as that used in a laser printer and the intensity of the laser is modulated constantly by a current delivered by a voltage controlled oscillator (VCO) 31 which generates a triangular wave

shape. The diagram A at the bottom of Figure 3 illustrates the radiance shape of the transmitted laser beam in the time domain. The fundamental oscillating frequency of the oscillator 31 is set to a value which is higher than the highest expected repetition frequency, e.g. 15 kHz. The mean laser intensity is controlled by an automatic power control (APC) 32 with the aid of the laser intensity detector 33 found in present day standard diode-type lasers.

The Figure 3 embodiment also includes a microprocessing unit (MPU) 34, which is divided into several blocks in this illustration, all of which are identified by the same reference numeral, since they represent one and the same unit. The microprocessor has an input which receives from the laser head 48 a signal which represents the temperature of said head and which steers a laser temperature drive means 45 for servo-regulating a Peltier-element 46 on the laser head. In a starting-up sequence, the microprocessor (MPU) 34 seeks a continuous sweep area which is free from any laser mode jump, with the aid of a mode jump detector 35. This is effected by adjusting the laser temperature thermoelectrically, until a mode jump is localized in the region of the minimum drive current. The residual sweep should then be continuous. Alternatively, the pre-set values can be used for the working temperature. In this case, the mode jump detector 35 is corresponded by the photo-current emanating from a detector which belongs to a glass etalon of low finesse and a thickness of less than one millimetre. Each mode jump will register as an abrupt discontinuity in this current, which is detected upon passing through a high-pass filter. Diagram B at the bottom of Figure 3 illustrates an example of this current prior to filtration. The mode jump is represented by the pulse-like parts, which are negative in the diagram but which in other cases may be positive. The time constant for this stabilization of temperature

through mode jump localization is of the order of magnitude of seconds.

A high-finesse etalon which defines the wave number sweep during the measuring processes, is adjusted automatically at 36, so that its transmission spikes are centered within the sweep interval, as illustrated in diagram C at the foot of Figure 3, beneath a reference detector 37 corresponding to the detector 17 in Figure 1. This is effected by carrying out phase comparison with the modulating VCO-signal arriving from block 31. The deviation signal in the circuit 36 rotates a galvanometer, which tilts the etalon. The time constant in this feedback circuit is in the order of magnitude of seconds.

When both of these functions are stable, the system is ready to carry out measurements, as soon as tracking is established in a phase-locking loop (PLL) 38. This phase locking loop modifies the laser sweep frequency, such as to obtain an appropriate fringe frequency in the object beam, detected by the object fringe detector 41, of 15 MHz for instance. The output signal from the phase locking loop 38 is amplified in an amplifier 39 and steers the voltage controlled oscillator 31. The reversed wave number sweep accelerates at each end-of-sweep of the oscillator 31. The high fundamental oscillating frequency of the oscillator 38 will ensure that the interference frequency of the object beam will pass the 15 MHz range. When this takes place, and provided that the signal/noise ratio is satisfactory, the phase-locked loop 38 will lock and regulate the frequency of the oscillator 31, by feedback through the FM-input of the oscillator. At the next end--of-sweep, the phase-locked loop 38 will lose the track and the procedure is repeated.

Provided that the phase-locked loop 38 is locked, which

state is indicated by a locking indicator circuit 47, a signal (from the circuit 47) is fed to the microprocessor 34 which, in turn, sends a clear-signal to a counter 40. This is supplied with an output signal from an oscillator 44 of relatively high frequency, e.g. 120 MHz. The choice of frequency is not critical, but the higher the better. The upper frequency limit is governed by the ability of the counter to count the pulses emanating from the oscillator 44.

The counter 40, however, does not begin to count immediately after receiving a clear-signal from the MPU 34, but waits in readiness for receipt of a start signal from the logic 43, whereupon it begins to count.

The oscillator is intended to function as a clock signal generator of high resolution. It is this oscillator which controls the apparatus and which is responsible not only for control of the wave number interval, but also simultaneous control of the time.

Since it is the main control pulses (the clock pulses) of 120 MHz which are counted and not that which leaves the object detector 41 direct, brief disturbances, such as spikes, transients, or erroneous interference fringes, will have little or no effect on the measuring result. It is the output signal from the oscillator 44 which is divided in a frequency divider 42 and fed to the reference input on the phase locked loop 38.

The comparator level for the high-finesse etalon signal follows the laser intensity form for a precise determination of the measuring wave number interval. Due to the presence of the etalon-centering system, a stop pulse from a start/stop logic circuit 43 in the end-of-count interval will always reach the counter 40 before the end-of-sweep

of the voltage steered oscillator 31. This stop pulse will activate the data transfer to the microprocessor 34, in which the accepted sweeps are stored for further processing and for calculating mean values on the basis of the equations (8) and (9) above.

As will be understood, instead of having solely one measuring interval within the laser sweep range, it is also possible to divide each wave number sweep into a number of intervals, by selecting a corresponding, thicker high-finesse etalon. The advantage afforded by such a solution is obvious, in those instances when the detection signals are weak and the phase-locked loop 38 is unsuccessful in locking over the entire sweep. Small parts can still be used and sampled, when the wave number markings lie close together. Furthermore, the smaller the free spectral range of the etalon, the more defined are the etalon transmission trigger points in the wave number domains.

The costs of manufacturing an inventive distance measuring apparatus can be kept low. This is because the interferometer is based on ready-to-use mass produced components. The transmitter including laser, collimator, beam splitter and quarter ($\lambda/4$) wavelength plates may be the same as those used in a CD-player. If audiofrequencies can be accepted for fringe detection, it is actually possible to use a complete CD-player, including its detector system with quadrant detector for servo-control of automatic focusing, automatic preamplification level of the audio switching signal for optimum digitilization of, in this case, interference fringes instead of CD-etched hole information. Otherwise, more advanced receiver units with conversion to standard TTL-pulses are available in the telecommunication field.

A simple microprocessor can be used to control the system.

It will be understood that the invention is not restricted to the aforedescribed embodiment and that this embodiment can be modified with the inventive concept as defined by the following claims.

The potential fields of use of the invention are innumerable, due not least to the low manufacturing price that can be achieved. Available instruments can be either too expensive, too bulky or too accurate for certain applications.

One large field in which the inventive concept can be applied is that of surveying or assaying old buildings, e.g. for reconstruction and the like. A "laser radar" connected to a CAD-system would be able to produce basic drawing data within an hour, whereas a present day firm of architects might take a week.

The speed at which the laser interferometer operates also enables the inventive system to be used for industrial process control purposes and for assembly line product control purposes.

As before mentioned, there are many possibilities for use of the inventive concept within the field of fibre optic sensors. The possibility of switching between scanning and stabilized laser function also increases the possibilities of achieving various different flexible solutions.

CLAIMS

1. A method for measuring an optical distance with the aid of a light beam transmitter (2) which, at least during a measuring operation, generates a continuous, coherent, electromagnetic light beam, parts of which are each transmitted along a respective one of two beam paths (3, 4, 8, 7 and 3, 4, 5, 6, 7) and rejoined in a detector (10) and there added one to the other, in which method the beam transmitter (2) during at least one sequence for establishing a discrepancy between the beam paths is caused to change its wave number in time, and in which a phase shift corresponding to a momentary wave number is registered in an output signal from the detector (10), and in which the number of occurrent interference fringes are counted (10) and/or the time is measured during a given sequence, as a measurement of the phase shift and therewith of the discrepancy between the optical paths, characterized in that the change in wave number of the beam transmitted by the transmitter (2) is selected within a predetermined, accurately delimited wave number interval; and in that said discrepancy is determined from the dependence of the phase shift on the change of wave number and/or the time.

2. A method according to Claim 1, characterized by establishing and combining at least two of the following measuring procedures for the purpose of compiling at least two equations which can be suitably combined to enable both the distance to the object and any movement of the object to be calculated:
A. measuring the time for the wave number change within the well-defined wave number interval during a separate sequence;
B. measuring during a separate sequence the time for the wave number change with reversed sign in relation to the

case under procedure A within a well-defined wave number interval, which need not be the same as that under procedure B;

C. counting fringes over a given time period at a fixed wave number and during a separate sequence;

D. holding the fringe pattern at the detector stable, by changing the absolute frequency of the laser so as to maintain said stability, and measuring the time during a given wave number interval.

3. A method according to Claim 1 or Claim 2, characterized in that an arrangement for producing a direct unit of measurement for the wave number interval includes a high--finesse reference interferometer.

4. A method according to Claim 1 or Claim 2, characterized in that an arrangement intended to produce a direct unit of measurement of the wave number interval produces this interval through a facility for indicating atomic or molecular resonance frequencies in a gas.

5. A method according to Claim 3 or Claim 4, characterized by delimiting the wave number interval with the aid of delimiting reference output signals from the unit measurement producing arrangement.

6. A method according to any of the preceding claims, characterized in that the interference fringes arriving from the detector (10; 41) are counted indirectly, by counting clock pulses whose frequency has a fixed relationship to the fringe frequency.

7. Apparatus for measuring an optical distance with the aid of a light beam transmitter (2) which is operative in generating a continuous, coherent, electromagnetic light beam at least during a measuring operation, parts of said

beam being transmitted along a respective one of two beam paths (3, 4, 8, 7 and 3, 4, 5, 6, 7) and joined together in a detector (10) and there added to one another, which apparatus includes a wave number changing arrangement which steers the transmitter (2) during at least one sequence, such as to cause said transmitter to change its wave number in time, in order to determine a discrepancy between said beam paths; means for registering a phase shift in a detector output signal, said phase shift corresponding to a momentary wave number; and in which apparatus the number of occurrent interference fringes are calculated in a counter (10) and/or the time is measured during a given sequence to provide a measurement of the phase shift and therewith the discrepancy between the optical paths, characterized in that the wave number change of the beam transmitted by the transmitter (2) is selected within a predetermined, accurately delimited wave number interval; and in that an evaluating means is provided for determining said discrepancy from the dependency of the phase shift on the wave number change and/or the time.

8. Apparatus according to Claim 7, characterized by an arrangement which is effective in providing a direct unit of measurement of the wave number interval and which includes a reference interferometer (9) of high finesse.

9. Apparatus according to Claim 8, characterized in that the reference interferometer is an etalon, e.g. an air etalon or a solid etalon.

10. Apparatus according to Claim 8, characterized in that the reference interferometer is of the Fabry-Perot kind.

11. Apparatus according to Claim 8, characterized in that the reference interferometer is a confocal interferometer.

12. Apparatus according to Claim 7, characterized in that the arrangement for giving a direct unit of measurement of the wave number interval produces this interval by indicating atomic or molecular resonance frequencies in a gas.

13. Apparatus according to any of Claims 8-12, characterized in that delimiting reference signals from the measurement producing arrangement are used to delimit the wave number interval.

14. Apparatus according to any of Claims 7-13, characterized in that the interference fringes from the detector (10; 41) are counted indirectly by counting clock pulses, the frequency of which have a fixed relationship with the fringe frequency.

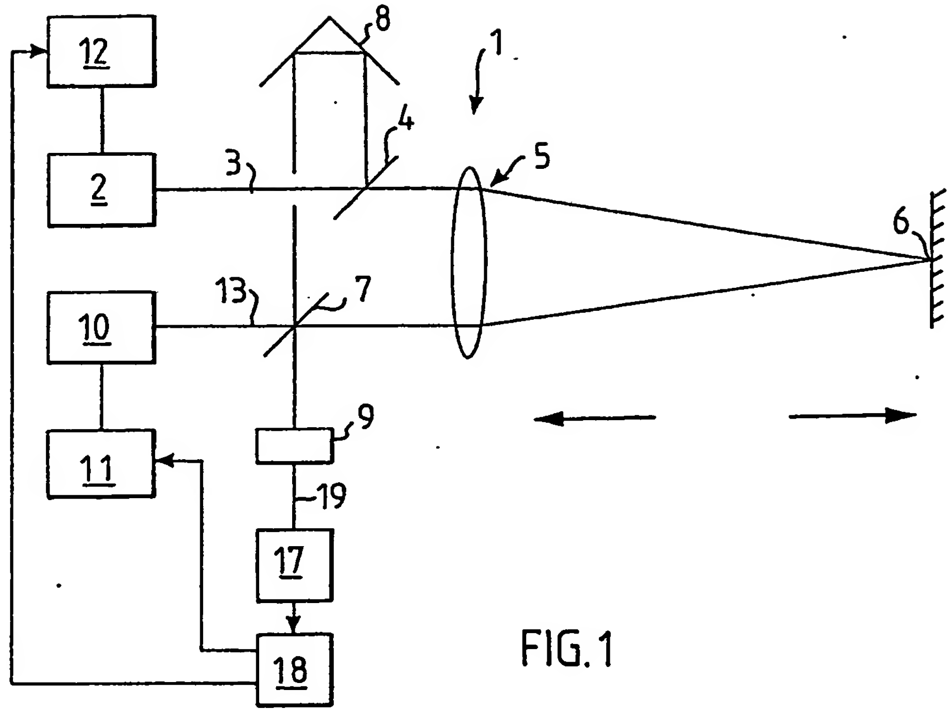

FIG.1

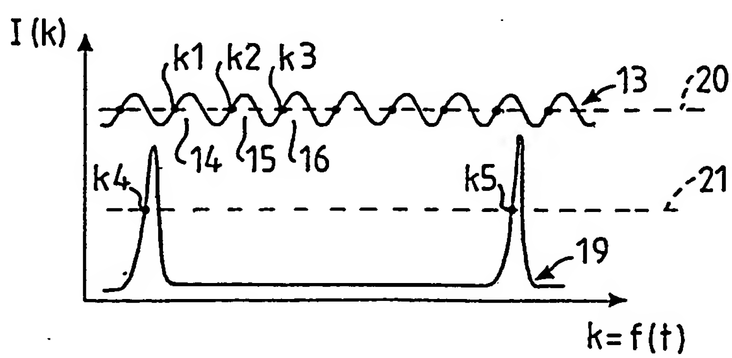

FIG.2

SUBSTITUTE SHEET

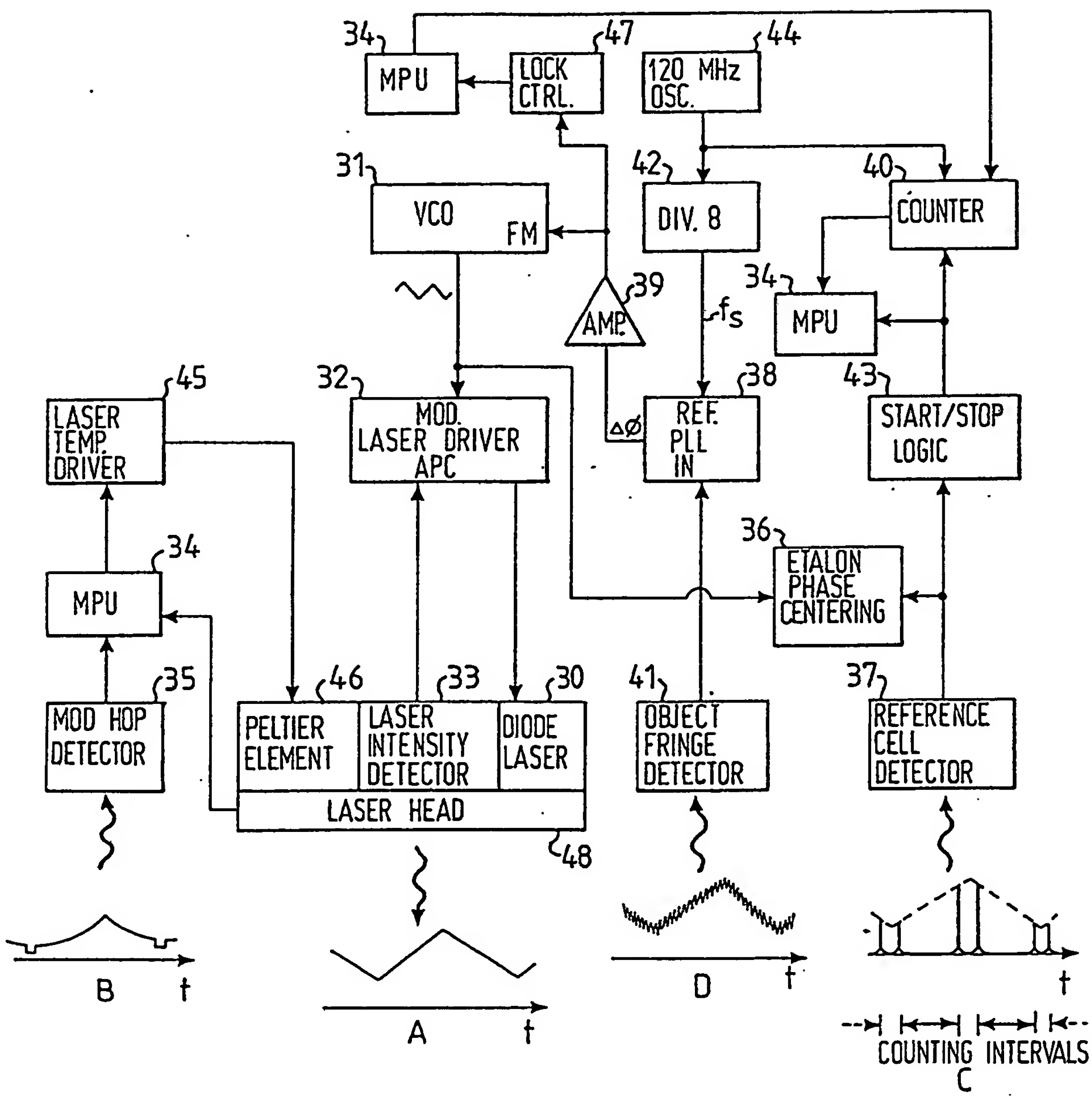
MPU
LOCK CTRL.
120 MHz OSC.
VCO
FM
DIV. 8
COUNTER
AMP.
f_s
MPU
LASER TEMP. DRIVER
MOD. LASER DRIVER APC
REF. PLL IN
START/STOP LOGIC
ETALON PHASE CENTERING
MPU
MOD HOP DETECTOR
PELTIER ELEMENT
LASER INTENSITY DETECTOR
DIODE LASER
LASER HEAD
OBJECT FRINGE DETECTOR
REFERENCE CELL DETECTOR
B
A
D
COUNTING INTERVALS
C

FIG.3

INTERNATIONAL SEARCH REPORT

International Application No PCT/SE89/00009

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC4

G 01 B 9/02

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC 4	G 01 B 9/02; G 01 J 9/02; G 01 S 17/32, 17/36
US Cl	356:3-5, 106, 108, 109, 345, 349, 355-358

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

SE, NO, DK, FI classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	US, A, 4 594 003 (SOMMARGREN) 10 June 1986	
A	Applied Optics, Vol. 26, No. 21, issued November 1987, A.J. den Boef " Interferometric laser range-finder using a frequency modulated diode laser", see pages 4545-4550.	

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
1989-03-17	1989 -03- 2 9
International Searching Authority	**Signature of Authorized Officer**
Swedish Patent Office	Ingemar Josefsson